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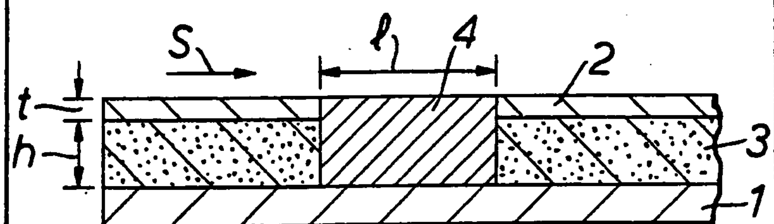
(54) **Microwave Attenuator Device**

(57) A microwave attenuator having a broad band attenuation characteristic is described in which an insert of conductive material (4) is substituted for a strip conductor (2) and the dielectric layer (3) of a predetermined length of transmission line of microstrip configuration. The insert (4) forms a lossy section having planar interfaces with the dielectric layer, the dimensions and characteristics of the insert satisfying the following condition for a wide range of angular frequency ω:

$$R \gg \omega L$$
$$G \gg \omega C$$
$$\sigma \gg \omega \varepsilon''$$

where R, L, G, and C are the resistance, inductance, conductance and capacitance per unit length of the lossy transmission line section, σ is the real component of the electrical conductivity of the insert material and $\omega\varepsilon''$ is the effective conductivity due to polarisation losses in the insert material.

FIG.3.



The drawing originally filed was informal and the print here reproduced is taken from a later filed formal copy.

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FIG.1.

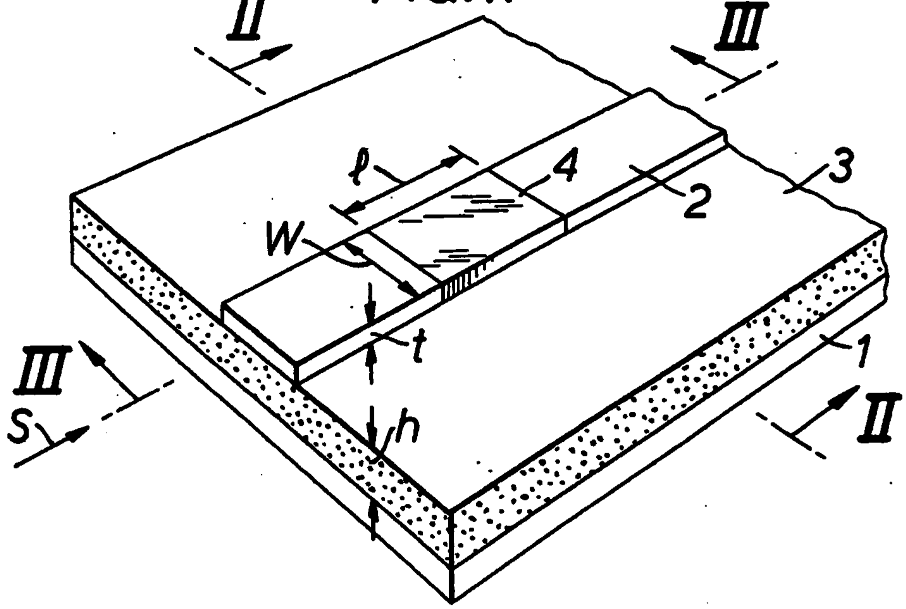


FIG.2.

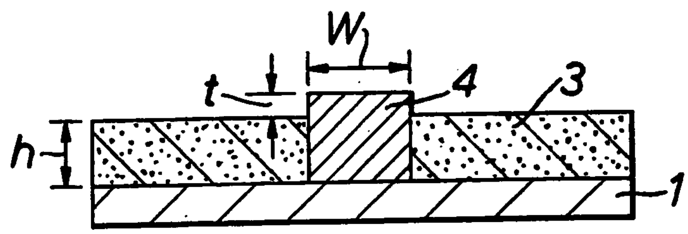
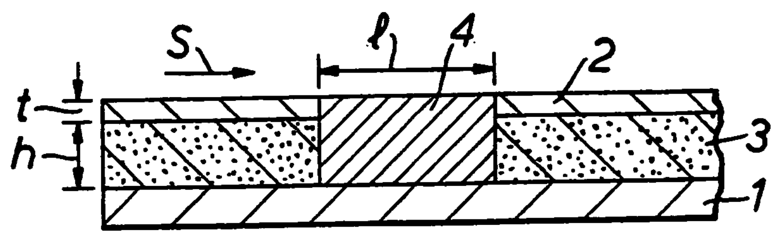


FIG.3.



SPECIFICATION

Microwave Attenuator Device

This invention relates to microwave attenuator devices.

Various types of microwave attenuator are known. Most of these rely upon the insertion of a lossy conductive element into a signal-carrying dielectric or cavity of a transmission line or waveguide. For example, a well-known attenuator is the "Card" attenuator consisting of a conductive layer on a substrate, often used in coaxial transmission lines.

An object of the present invention is to provide a simple microwave attenuator device with a broadband attenuation characteristic.

Accordingly the present invention provides a microwave attenuator device comprising a length of transmission line having a conductor and at least one conductive element, between which a dielectric layer is interposed, and a lossy insert of conductive material which is substituted for the conductor and for the dielectric layer over a predetermined section thereof, the insert having planar interfaces with the dielectric, perpendicular to the transmission direction, and the dimensions and the electrical parameters of the insert being such that the transmission line characteristics of the lossy section satisfy the following set of conditions for a wide range of angular frequency ω:

$$R \gg \omega L$$

$$G \gg \omega C$$

$$\sigma \gg \omega \varepsilon''$$

where R,L,G,C are the resistance, inductance, conductance and capacitance per unit length of the lossy transmission line section, σ is the real component of the electrical conductivity of the insert material and $\omega\varepsilon''$ is the effective conductivity due to polarisation losses in the insert material, which has a complex dielectric permittivity

$$\varepsilon' - j\varepsilon''$$

whereby the device exhibits attenuation characteristics which are substantially independent of frequency over the range of frequencies for which R and G are frequency-independent.

The invention is particularly, but not exclusively, applicable to transmission lines of microstrip configuration, in which case the dielectric layer comprises a substrate interposed between a base or groundplane conductive element and a strip conductor, the lossy insert being substituted for part of the strip conductor and extending through the underlying dielectric substrate and being connected electrically to the groundplane conductor.

The invention may alternatively be applied to a length of transmission line having a stripline or coaxial line configuration.

In the preferred microstrip configuration of the attenuator device the base or groundplane conductive element, having an extensive area compared with the strip conductor, acts as an integral heat sink. This gives the device good heat-dissipating characteristics so that for a given power consumption the device can be made smaller than comparable previously known attenuator devices. The lossy insert may be applied to the groundplane conductive element as a coating of conductive material, for example graphite in suspension, applied as a paint. The transmission line may be fabricated by selective removal of a conductive layer on both sides, to leave the strip conductor on said one side, a hole of the requisite dimensions being made in said conductor and the underlying dielectric layer and subsequently filled with conductive material to form the lossy insert.

The lossy insert may be provided in the form of a prefabricated chip which is dropped into a hole made in the strip conductor and underlying dielectric layer of a microstrip and secured using, for example, electrically conducting adhesive. Since the insert makes direct electrical contact with the groundplane conductive element an attenuator is formed with good thermal and electrical connection to the groundplane conductive element, avoiding any problems associated with the earthing of the insert.

The attenuator device according to the invention, being of simple construction, is potentially inexpensive and suitable for mass production. The attenuation of the device is virtually independent of temperature. Its broadband attenuation characteristics render the device suitable for various practical applications, including isolation or power level reduction of signal sources, and the reduction of the standing wave ratio (SWR) at the insertion point of microwave measurement or monitoring equipment. The device can also be used for extending the range of microwave power meters.

It will be appreciated that the attenuator device according to the invention can also be used as a termination for a microstrip or other transmission line.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying and purely diagrammatic drawings, in which:—

Figure 1 is a broken away perspective view of part of a microstrip transmission line incorporating a microwave attenuator device in accordance with the invention;

Figure 2 is a transverse cross-section of the attenuator device, taken on line II—II in Figure 1, and

Figure 3 is a longitudinal section of the attenuator device, taken along III—III in Figure 1.

The drawings illustrate part of a microstrip comprising a base or groundplane conductive element 1 and an upper strip conductor 2

separated by a dielectric substrate 3. The dielectric substrate 3 has a conductive layer on one face acting as the groundplane element 1, which acts as a heat sink. The direction of signal propagation along the strip conductor 2 is indicated by arrow S in Figure 1.

The attenuator device according to the invention is formed by the replacement of a short section of the conductive element 2 by a lossy insert 4 of conductive material which is also substituted for a section of the underlying substrate 3, so that the lossy insert 4 interconnects the strip conductor 2 and the groundplane element 1 electrically, the insert 4 having interfaces with the dielectric substrate 3 which are planar and perpendicular to the transmission direction.

A section of microstrip transmission line incorporating the attenuator device according to the invention may be fabricated by the selective etching of a double-sided copper-clad dielectric sheet, such as a double-sided printed circuit board, as so as to form the strip conductor 2. A short section of the conductor 2 is then removed, and a hole is made in the underlying dielectric substrate 3. The rectangular section lossy insert 4 is then introduced into the hole. Typically, the printed circuit board would have a total thickness less than 1 mm, with copper cladding of thickness 40μm. The width W of the strip conductor 2 in one example was 1.57 mm; the length l of the conductive insert 4 was 2.8 mm and the required conductivity σ of the lossy material forming the insert 4 was 12.5S.m^{-1}. A suitable conductive material for the lossy insert 4 is a suspension of graphite for example "ELECTRODAG" 580 (Trade Mark) having a normal conductivity of 20.S.M^{-1} manufactured by Acheson Colloids and applied by painting.

The material of the lossy insert 4 and its dimensions are chosen so as to give a desired attenuation characteristic with impedance matching over a broad frequency band (d.c. to high microwave frequencies). The principle of design of the attenuator device is as follows.

Known expressions for the characteristic impedance Z_0 and propagation constant γ of a transmission line are;

$$Z_0=\sqrt{\frac{R+j\omega L}{G+j\omega C}} \qquad (1)$$

$$\gamma=\sqrt{(R+j\omega L)\quad(G+j\omega C)} \qquad (2)$$

where R,L,G and C are the transmission line parameters as defined previously, and ω is the angular frequency.

To produce a broadband attenuator the following conditions must be satisfied:

$$R\gg\omega L \qquad (A)$$

$$G\gg\omega C \qquad (B)$$

In this case, the attenuation constant α becomes:

$$\alpha=\sqrt{RG} \qquad (3)$$

and the characteristic impedance Z_0 becomes:

$$Z_0=\sqrt{\frac{R}{G}} \qquad (4)$$

It will be seen that the frequency-dependence of the parameters of α and Z_0 depends upon the frequency-dependence of G and R. If the thickness of the lossy insert is less than the skin depth both the expressions 3 and 4 will become frequency-independent. In the case of a lossy substrate, however, the conductance G is frequency-dependent and as a result the attenuation constant α and the characteristic impedance Z_0 are both frequency-dependent. Thus for lossy substrates:—

$$G=\frac{\omega\varepsilon''+\sigma}{\varepsilon'}\,.\,C \qquad (5)$$

where $\omega\varepsilon''$ is the effective conductivity due to polarisation losses in a conductive substrate having a complex dielectric permittivity $\varepsilon'-j\varepsilon''$ and where σ is the real electrical conductivity of the substrate.

If the condition:

$$\sigma\gg\omega\varepsilon'' \qquad (C)$$

is met, then equations, (3) and (4) above give the following expressions for the attenuation constant α and the characteristic impedance Z_0:

$$\alpha=\sqrt{\frac{RC\sigma}{\varepsilon'}} \qquad (6)$$

and

$$Z_0=\sqrt{\frac{R\varepsilon'}{C\sigma}} \qquad (7)$$

It will be seen that both expressions (6) and (7) are frequency-independent, so that for a broadband attenuator the necessary conditions may be expressed as the three conditions (A) (B) and (C) above.

In the specific example illustrated, where the dielectric substrate 3 has a thickness h, the upper strip conductor 2 has a thickness t and a width W, and the lossy insert 4 has a length a, the following expressions may be derived for the characteristic resistance and impedance of the line incorporating the lossy insert:

$$R=\frac{1}{\sigma W(h+t)}\ \text{Ohm.m}^{-1} \qquad (8)$$

$$G=\frac{\sigma W}{(h+t)} \quad S.m^{-1} \qquad (9)$$

The attenuation constant α is given by:

$$\alpha=\sqrt{RG}=\frac{1}{(h+t)} \text{nepers.m}^{-1} \quad (10)$$

and the characteristic impedance Z_0 is given by

$$Z_0=\sqrt{\frac{R}{G}}=\frac{1}{\sigma W} \text{ Ohms} \qquad (11)$$

Both expressions (10) and (11) are frequency-independent providing the height $(h+t)$ of the lossy material is less than a skin depth and the conductivity σ of the lossy material meets condition (C) above.

Claims

1. A microwave attenuator device comprising a length of transmission line having a conductor and at least one conductive element, between which a dielectric layer is interposed, and a lossy insert of conductive material which is substituted for the conductor and for the dielectric layer over a predetermined section thereof, the insert having planar interfaces with the dielectric, perpendicular to the transmission direction, and the dimensions and the electrical parameters of the insert being such that the transmission line characteristics of the lossy section satisfy the following set of conditions for a wide range of angular frequency ω:

$$R \gg \omega L$$

$$G \gg \omega C$$

$$\sigma \gg \omega \varepsilon''$$

where R,L,G,C are the resistance, inductance, conductance and capacitance per unit length of the lossy transmission line section, σ is the real component of the electrical conductivity of the insert material and $\omega\varepsilon''$ is the effective conductivity due to polarisation losses in the insert material, which has a complex dielectric permittivity

$$\varepsilon'-j\varepsilon''$$

whereby the device exhibits attenuation characteristics which are substantially independent of frequency over the range of frequencies for which R and G are frequency-independent.

2. A microwave attenuator device according to Claim 1, in which the length of transmission line has a microstrip configuration, the dielectric layer comprising a substrate interposed between a base or groundplane conductive element substituted for part of the strip conductor and extending through the underlying dielectric substrate and being connected electrically to the base or groundplane conductor.

3. A microwave attenuator device according to Claim 1 in which the length of transmission line has a stripline or coaxial line configuration.

4. A microwave attenuator device according to Claim 2, in which the base or groundplane conductive element has an extensive area compared to the strip conductor and acts as a heat sink.

5. A microwave attenuator device according to Claim 2 or Claim 4, in which the lossy insert is applied to the base or groundplane conductive element as a coating or conductive material, for example graphite in suspension.

6. A microwave attenuator device according to Claim 2 or Claim 4, in which the transmission line is fabricated by selective removal of a conductive layer from one side of a dielectric layer which is clad with a conductive layer on both sides, to leave the strip conductor on said one side, a hole of the requisite dimension being made in said conductor and the underlying dielectric layer and subsequently filled with conductive material to form the lossy insert.

7. A microwave attenuator device substantially as herein described with reference to and as shown in the accompanying drawings.

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